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Performance of Constructions with Clay Plaster and Timber at Elevated Temperatures

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Abstract

The combustibility of timber is one of the main reasons that too many building regulations and standards restrict its use. Lack of understanding of the fire technical properties of clay plaster is what most likely prevents this traditional material in combination with timber from being widely used. The purpose of the following research is to designate the fire technical properties for clay plaster for the fire design of timber structures. For this study the fire testing of clay plaster was carried out in small and model scale to determine the main characteristics. In this paper the recommendations for the improvement of the design method for timber structures with clay plaster according to the safety philosophy of Eurocode 5 Part 1-2 are published.

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Keywords: timber constructions ; fire design ; clay plaster ; EN1995-1-2 ; cross-laminated timber

1. Introduction

There is an increasing challenge to reduce the energy and environmental impacts from the construction sectors. It has been recognized that traditional and ecological building materials could be perfect for utilizing sustainable design principles. Timber as one of the most versatile renewable resources and large-scale construction materials is acknowledged to have a great potential to improve the development of energy efficient buildings. Innovative new

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building technologies and development in product design enable a wide range of different solutions in timber constructions that minimize the future environmental impact.

In addition, the demand for a more sustainable and healthier indoor environment is increasing. Therefore, there has been a growing interest in nontoxic, reusable and recyclable materials together with low embodied energy. At the same time in order to reduce the operational energy use in built environment, the passive role of building materials has become an important factor to investigate. It has been scientifically explained that exposed surfaces of clay plaster act as a passive regulator of internal humidity level due to its excellent hygroscopic and vapour permeable properties [1].

Historically, clay plaster has been used in various construction techniques with timber. Clay has been neglected by modern materials in the last decades but it has been once again recognized and there is a growing interest towards a wider use of clay products. However, nowadays the restrictions of the fire design of timber structures are one of the main reasons for limiting the use of traditional materials. Fire safety has been one of the earliest issues addressed by building regulations and is currently an essential parameter to be investigated in building design.

In general, one of the main obstacles for the wider use of timber is the combustibility of timber. The standard for structural fire design of timber structures, EN 1995-1-2 [2], provides some information for protection materials but it has no information concerning plasters. This is most probably because of the minimal amount of knowledge about the fire technical properties of clay plaster in conjunction with timber structures.

The fire resistance of timber is generally determined by full-scale furnace testing. However, full-scale testing is highly complex and expensive tool for the verification of the fire resistance of different timber combinations. In this presented study, a small scale testing appeared to be the most reasonable testing method to examine the basic properties of clay plaster as a fire protection material since there are a large number of possible combinations of timber and different mixtures of clay plaster available.

In this paper a short introduction about the main conception of the fire design of timber structures and clay plaster as a protection material is presented. For this study the fire testing of clay plaster was carried out in small and model scale to determine the main characteristics of clay plaster which influence the fire technical properties of clay plaster the most. A short overview of the initial study on protective effect of clay plaster in small scale investigated by Liblik in her master thesis [3] is introduced. The results of this paper provide future development in a wider use of natural building materials.

Nomenclature

t	time (min)
t_{ch}	start time of charring (min)
$d_{\mathrm{char.0}}$	charring depth for one-dimensional charring (mm)
d	thickness of timber member (mm)
h_{p}	plaster thickness (mm)
β_0	one-dimensional charring rate (mm/min)
$\beta_{0.2}$	reduced one-dimensional charring rate (mm/min)
k_2	protection phase factor
T	temperature (˚C)

2. Design of timber structures

2.1. Design principles

The fire design of timber structures is specified in EN 1995-1-2 [2]. It describes the principles, requirements and rules for the structural design of timber structures exposed to fire.

One of the main objectives of structural fire safety is to guarantee the load-bearing capacity of the structure for a required period of time. The required time is specified by the building regulations. The resistance to fire concerns structural elements which must withstand a fully developed fire while fulfilling certain requirements. The fully developed fire is described by the standard temperature-time curve given in ISO 834 [4]. Charring is generally the dominating effect influencing the mechanical resistance of timber structures since cross-section of a timber member is reduced by fire.

According to EN 1995-1-2 [2] charring of wood shall be taken into account for all surfaces of timber directly exposed to fire and for surfaces initially protected from fire exposure, but where charring of timber occurs during a relevant time of fire exposure. Important design parameters for different protection materials stated in EN 1995-1-2 [2] are the start time of charring, charring rate at the protected charring phase and post-protection charring phase as well as the failure time of protection.

The verification of fire resistance of timber elements can either be based on the large-scale fire tests, or on calculations according to EN 1995-1-2 [2], performed in conjunction with the respective national application documents.

2.2. Behaviour of timber in fire

When sufficient heat is applied to wood, chemical degradation takes place with the resultant formation of charcoal and combustible gases, accompanied by a loss in mass. EN 1995-1-2 [2] specifies that the temperature value of 300°C is agreed to be taken as the start time of charring t_{ch}.

For timber surfaces unprotected throughout the time of fire exposure, the residual cross-section can be calculated by a constant basic charring rate β_0, see Fig.1 (a). The charring rates are specified in EN 1995-1-2 [2].

The charring depth $d_{\mathrm{char,0}}$ is the distance between the outer surface of the original member and the position of the char-line, see Fig.1 (b). It should be calculated from the time of fire exposure and the relevant charring rate. According to EN 1995-1-2 [2] the charring rate for one-dimensional charring of timber should be taken as constant with time, see the equation below

$$d_{\mathrm{char.o}} = \beta_0 \cdot t \tag{1}$$

While timber surface is initially protected from fire exposure the start time of charring is delayed and the charring is slowed down in comparison to unprotected timber surfaces, see Fig.1 (a). When the charring of timber has started but the protection layer is still in place, there are expressions given in EN 1995-1-2 [2] to calculate the reduced charring rate $\beta_{0.2}$. The reduced charring rate is calculated by a protection phase factor k_2 which is multiplied to the charring rates of the unprotected timber members (2). It is important to note that the reduced charring rate is only applicable when the protection material is attached on timber.

$$\beta_{0,2} = k_2 \cdot \beta_0 \tag{2}$$

According to EN 1995-1-2 [2] a charring rate β_0 is taken as a basic value observed for one-dimensional heat transfer under ISO-fire exposure in a semi-infinite slab. Since large timber surfaces are usually exposed to fire on one side, the one-dimensional charring β_0 is taken as the basis of this study [5].

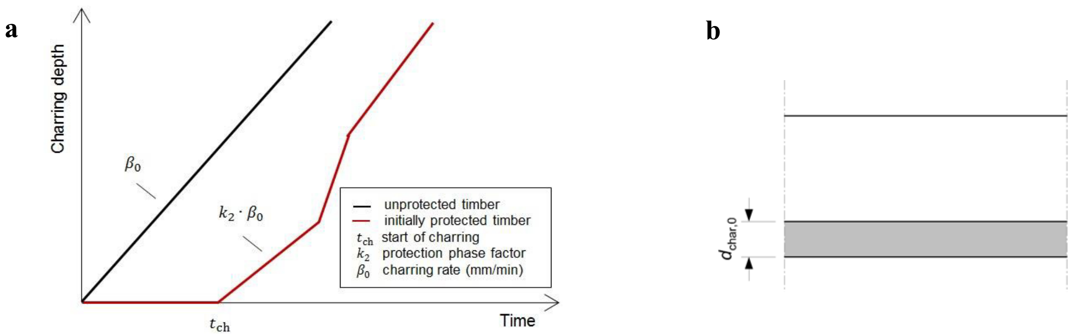

Fig. 1. (a) Charring of protected and unprotected timber; (b) Charring depth $d_{\mathrm{char,0}}$ for one-dimensional charring.

3. Clay plaster

Components of dry natural clay plaster are a fixed proportion of sand and silt, clay and some form of fibres. Sand and silt provide the structure, bulk and strength to the plaster. Clay acts as a binding agent for developing the binding and adhesive forces between sand and fibres. Natural fibers are added in order to resist the tensile stresses within the surface of plaster. There are various fibers which can be used as straw, cattail, flax, sawdust etc. [6].

Clay plaster has excellent vapour permeability and hygroscopic qualities. Of particular note, clay plaster could absorb a large amount of moisture from the air and releases it while the humidity level is low in the room. This is also due to the exposed thermal mass and hygroscopic properties that help buffer the temperature and relative humidity of the internal environment [1]

Water activates the binding forces of clay and is added to the dry mixture in the application process. Clay distinguishes themselves from other plasters as they harden by drying while the excess water added during mixing is lost. Thereby it can be re-worked when some water is added on the surface of clay plaster [6].

Since clay plaster does not chemically react with the substrate, the surface has to be sufficiently rough in order to develop a good physical bond. Therefore, plaster supports as a reed mat are widely used in order to ensure a good mechanical bond between the surface and the plaster.

Clay plaster can be applied on walls and ceiling in buildings by using tools and techniques common to conventional plasters. A plaster thickness maximum 10-15 mm is applied at once. Subsequent layers can be applied as the previous layer is firm.

There is no product standard for clay plasters on European level. However, a German standard DIN 18947 [7] for clay plaster was published in 2013.

4. Initial study

4.1. General

The aim of the initial study was to investigate the protective effect of clay plaster for the fire design of timber structures. In this study the main parameters for the fire design were determined - the start time of charring and the charring rate of timber members protected with plaster. This work has been carefully examined in master thesis of Liblik at TUT [3].

In this work, a small scale instrument was used to conduct the testing. Tests were performed at SP Technical Research Institute of Sweden in Stockholm. Previous studies have proven that Cone Calorimeter (ISO 5660) [8] is a dependable instrument to determine the properties of charring of timber members as a simulation of full scale furnace tests [9-11].

The study concentrated only on the basecoat of clay plaster with a reed mat on timber member. In order to receive a more comprehensive overview of the properties of clay plaster, different clay/sand ratios of components of clay plaster with a constant straw fibre consistent were tested. The range of plaster thicknesses was chosen by the practical use of plaster in buildings. For reference, gypsum plasterboard as a widely used fire protection material was tested and the results are presented in graphs below.

4.2. Test specimens

The dimensions of tested timber members were 100x100x100 mm which were set by the measurements of the retainer frame of Cone Calorimeter see Fig.2 (a). Timber members were instrumented with thermocouples to measure the temperatures under plaster throughout the testing. A reed mat was fixed on top of the timber specimen and covered with layers of plaster. Plastering was conducted mechanically by trowel.

Only a basecoat of clay plaster was tested with a grain size of 0 – 4 mm. Three different ratios of components of clay plaster were tested with plaster thicknesses of 10, 20, 30 and 40 mm. Testing comprised a double-testing for each unique specimen.

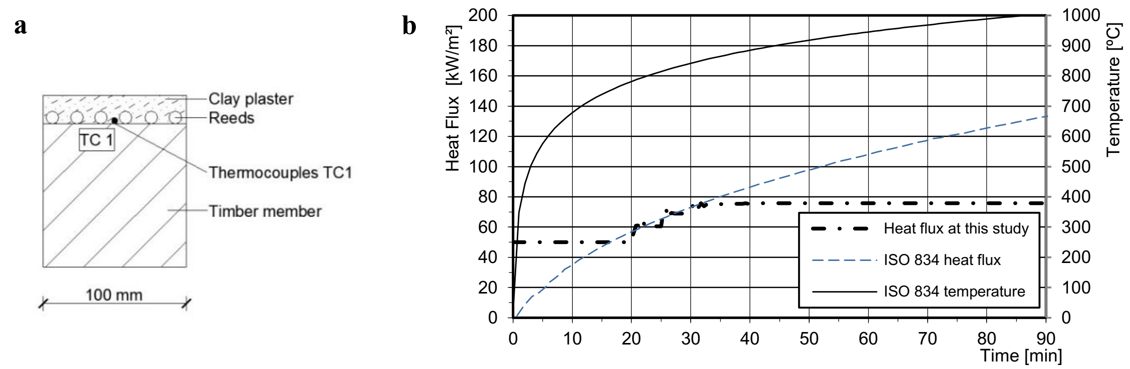

Fig. 2. (a) Schematic of a prepared test specimen; (b) ISO 834 temperature-time curve and heat flux curve at this study.

All materials used in this study were manufactured in Southern Estonia. The components of clay plaster were carefully processed by professional craftsman. Preparations of the specimens and plastering were conducted by professionals in Estonia. Prepared specimens were transported to Stockholm and conditioned in a controlled climate chamber before testing.

4.3. Test method

Cone Calorimeter (ISO 5660) [8]as a small-scale instrument was used to determine the charring of timber specimens. Temperature measurements were received by the mounted thermocouples. The charring rate was analyzed by the residual cross-sections of timber specimens.

The standard temperature-time fire exposure (ISO 834) [4] was followed by a heat flux during the most relevant time period to determine the start time of charring, see Fig.2 (b). It illustrates the heat flux curve which corresponds to the standard ISO 834 [4] temperature-time curve and is roughly followed by the heat flux at this study. The duration of each test was 60 minutes.

4.4. Results

A total of 24 specimens were tested with an additional test concerning gypsum plasterboard with a thickness of 15 mm. The temperature measurements indicated that the use of clay plaster as a protection layer increases the start

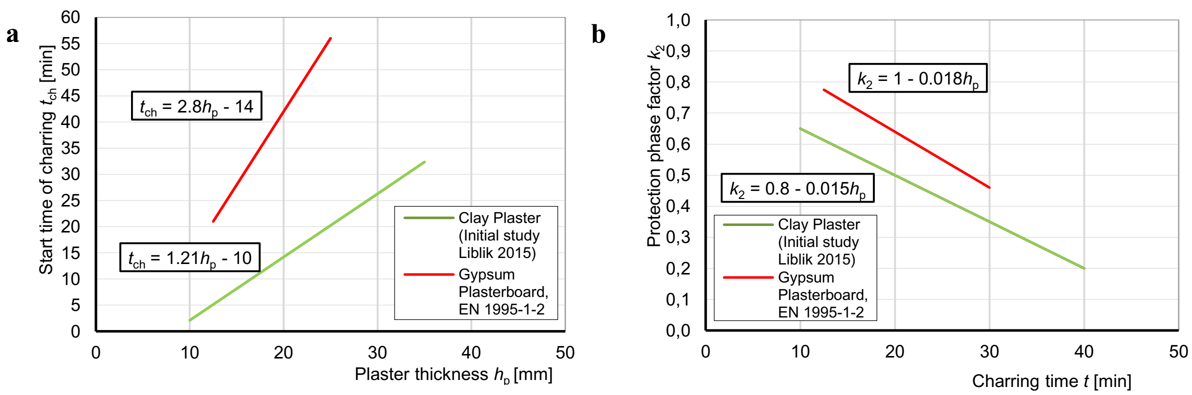

Fig. 3. (a) Comparison of the start time of charring between clay plaster and gypsum plasterboard; (b) Comparison of the protection phase factor between clay plaster and gypsum plasterboard.

time of charring of timber. The obtained values indicate that the main factor influencing significantly the protective effect of timber is the thickness of plaster, see Fig.3 (a). Different clay/sand ratios of components of clay plaster have a minimum effect on the charring behaviour of timber.

The proposed expressions for the calculation of the start time of charring of timber and the decreased charring rate are presented on the Figure 3. In addition, the Figures illustrate the comparison of properties of clay plaster with gypsum plasterboard. Fig.3 (b) shows the charring behaviour of timber under a protective layer. Lower value of the protection phase factor k_2 corresponds to a slower charring rate for timber. It can be concluded that the start time of charring is significantly increased when gypsum plasterboard is used, however the charring rate of timber protected by gypsum plasterboard is higher compared to clay plaster.

5. Small scale verification tests

5.1. Introduction

One of the main objectives of the initial study by Liblik [3] was focusing on the basic investigation of protective effect of clay plaster with different clay/sand composition ratios. No ready-mix products from the market were used. However, there is a large variability of clay plasters on the market from different manufacturers worldwide. Plasters are flexible in the use of different clay/sand ratios of components and types of clay, fibers and other additives. As a result, it is essential to compare the test results gained from the initial study with clay plasters on the market.

The verification tests in small scale are focusing on two types of ready-mix clay plasters by Estonian main manufacturers. Clay plaster only as a base coat with a grain size 0 – 4 mm is tested in order to compare the results to the initial study. This present testing with the Cone Calorimeter follows strictly the test methodology used in the initial study. The obtained results about the start time of charring and the charring rate of timber are presented and analyzed.

5.2. Test specimens

The preparation process followed strictly the steps of the initial study. Dimensions of each timber specimen were 100x100x100 mm. A reed mat as a plaster support was attached on the timber member and covered with clay plaster. All components of clay plasters were manufactured in Southern Estonia.

A total of 16 test specimens were prepared in Estonia by professional craftsmen. Two ready-mix plasters were tested with thicknesses ranging from 10 – 40 mm, see Table 1. One type of plaster with straw fibers has been tested to the German earth plaster standard DIN 18947 [7] and meets the standard of highest strength class SII. The second type of plaster from another manufacturer consists of cattail fiber instead of straw. In order to gain reliability of results a double-testing for each unique specimen was conducted. General rules of the application process were followed.

5.3. Testing procedure

Tests were performed at SP Technical Research Institute of Sweden in Stockholm. Specimens were conditioned in a controlled climate chamber at 20˚C and 65% RH about two weeks before testing. Testing was carried out with a Cone Calorimeter and the same steps were followed as in the initial study. Necessary equipment for testing of the specimens is shown in Fig.4 (a). Test specimens were sealed with an aluminum tape on the edges to prevent the air flow. Tests were carried out at horizontal orientation exposed directly to the heat flux using a retainer frame, see Fig.4 (b). Duration of each test was 60 minutes.

Test specimens were exposed to the heat flux corresponding approximately to the standard temperature-time curve fire exposure (ISO 834) [4]. The start time of charring of timber was measured by thermocouples. Thermocouples were located in the center and on top of the timber surface directly under plaster. Full contact was ensured by fixing the wires with staples. The charring rate was analyzed after the testing and cooling down the specimens by residual cross-section. A total of 16 specimens were tested.

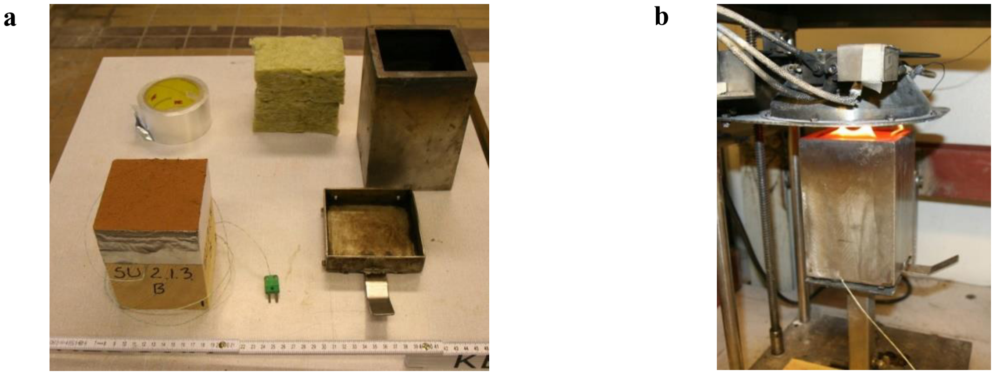

Fig. 4. (a) Prepared test specimen and equipment for the testing; (b) Testing in Cone Calorimeter.

Table 1.Prepared specimens for the small scale tests

Type of clay plaster	Natural fibre	Thickness of clay plaster [mm]				Double-testing
		10	20	30	40	
		Numbered test specimens				
Plaster 1 clay/sand/fibre	Chopped straw	2.1.1	2.1.2	2.1.3	2.1.4	A
		2.1.1	2.1.2	2.1.3	2.1.4	B
Plaster 2 clay/sand/fibre	Cattail	2.2.1	2.2.2	2.2.3	2.2.4	A
		2.2.1	2.2.2	2.2.3	2.2.4	B

5.4. Results and analysis

The temperature measurements indicate temperature rise on timber surfaces under plaster. Different thicknesses of plaster are well distinguished by different slopes of curves, see Fig.5 (a). Higher temperature curves relate to thinner thickness of plaster. Fig.5 (a) clearly illustrates that the protective effect of clay plaster is significantly influenced by the thickness of plaster. The evaporation of the moisture content in wood, a plateau at 100˚C is clearly recognized on thicker layers of plaster as the insulation capacity increases.

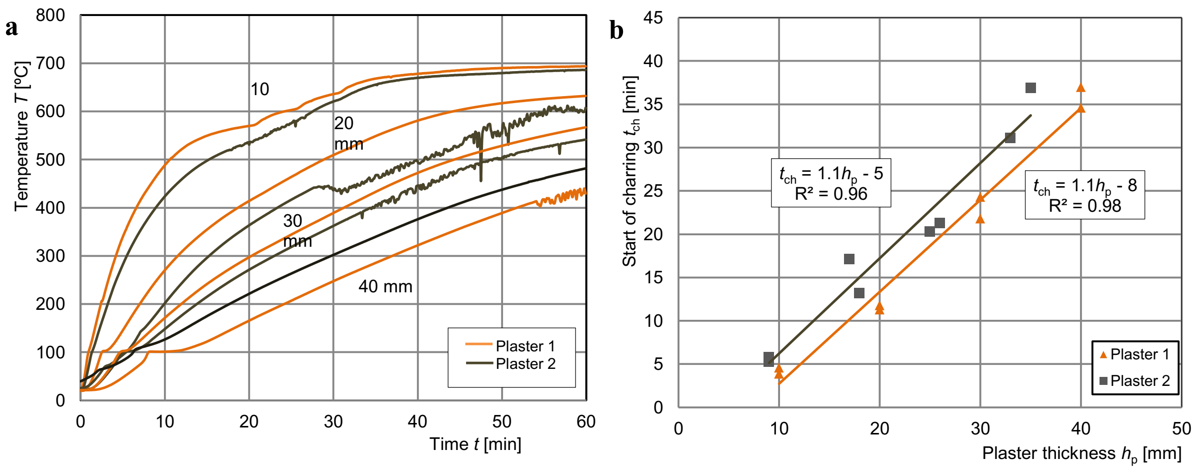

Fig. 5. (a) Comparison of temperature rise curves on the interface of timber and plaster; (b) Comparison of start time of charring.

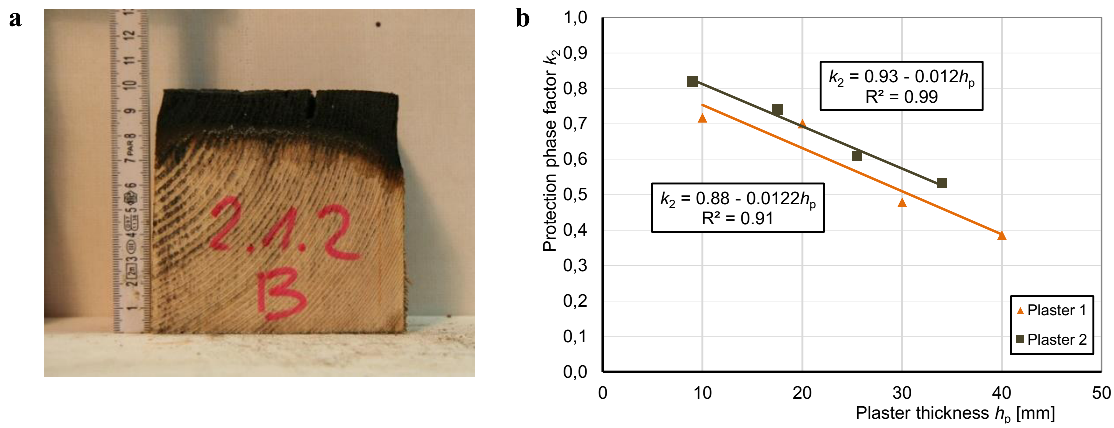

Fig. 6. (a) Documentation of a residual cross-section of a tested specimen; (b) Protection phase factor for the calculation of reduced charring rates.

There is a good repeatability of temperature curves of double-testing. Mean measured temperatures are presented for each thickness of plaster. Since two different mixtures of plaster were tested they are pointed out in different line colours, see Fig. 5 (a). This Figure illustrates that there is no significant difference in temperature measurements between two tested plasters. Slight differences in temperature measurements could be a result of different mixtures and thicknesses of plaster and the fiber content, but also the application technique by different craftsmen.

There is a slight inaccuracy of layer thicknesses, see the exact measured layer thicknesses on Fig.5 (b). This probably explains the slight differences in temperature measurements on Fig.5 (a).

Some bouncing lines can be detected from the graph. That is most probably caused by the combustion of timber. The temperature value of 300˚C is agreed to be taken as the start time of charring according to EN 1995-1-2 [2]. For each test the start times of charring were pinpointed from the data received from the thermocouples, respectively.

The relationship between the start time of charring and the thickness of plaster is shown on the Fig.5 (b). Important note is that both mixtures of plaster show a good linear regression, respectively. Although, the temperature measurements showed a good correlation between Plaster 1 and 2, the trend lines of the start time of charring show slight difference. Plaster 2 refers to the plaster with cattail fibers and indicates increased start time of charring compared to the Plaster 1 with straw fibers, see Fig.5 (b). The possible factors concerning the different results were discussed above. In this study the charring rate for timber members was calculated by the residual cross-section of timber and the time range from the start time of charring until the 60 minutes of test period.

No cracking or damage of the plaster coat was detected during and after the test. Test specimens retained their shape after cooling down. Plaster was removed from the timber member. Thereafter, timber specimens were sawn into two species along the centre line in order to measure the residual cross-section, see Fig.6 (a). The cut species showed a smooth plateau of charcoal in the middle of the timber member which corresponds to the one-dimensional charring. The charring depth is measured from the centre line where the thermocouples were placed. The charring rate is calculated from the relationship between the charring depth and the time of charring of timber. A mean protection phase factor was calculated from these results, see Fig.6 (b).

6. Model scale verification tests

6.1. Introduction

In this study two model scale tests were conducted with a cross-laminated timber (CLT) protected with clay plaster with thicknesses of 10 and 30 mm under ISO 834 fire exposure. A ready-mix clay plaster as a basecoat with cattail fibre was used. CLT was used to make the specimen comparable to the previous tests in small scale.

a b

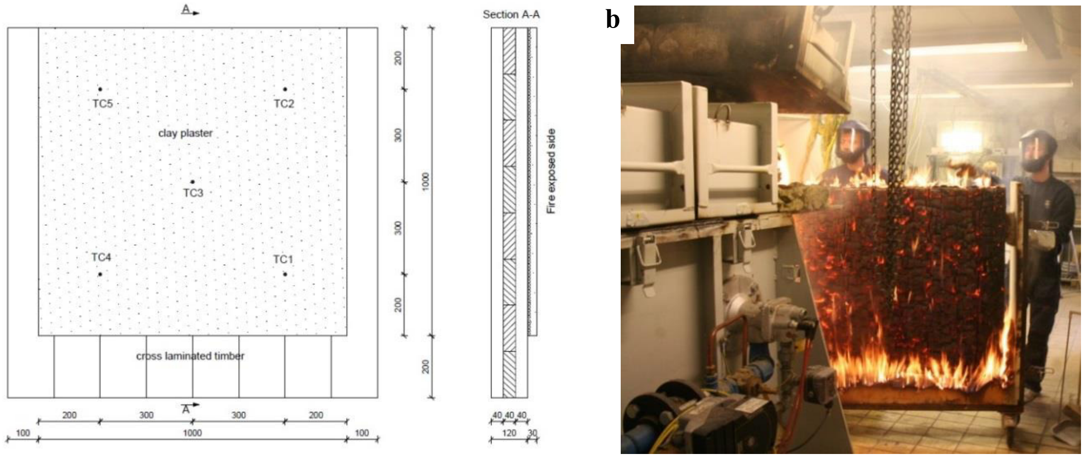

Fig. 7. (a) Plan and cross-section of the test specimen; (b) Test specimen after the test.

6.2. Experimental study

Tested timber specimens were 3-layered CLT panels with a total thickness of 120 mm. The dimensions of each board were 40 mm in thickness and 150 mm in width. A board thickness of 40 mm was chosen in order to ensure the solid timber effect in testing. The average density of timber was 451 kg/m³. The test specimens were prepared in Estonia by professional craftsman. Tests were carried out at SP Wood Technology in Sweden, Stockholm.

Vertically positioned specimen had an exposed clay plaster area of 1,0 x 1,0 m. A ready-mix clay plaster with cattail fibres without any finishes and paints was tested (Plaster 2 in small scale tests). Only a basecoat with a grain size of 0 – 4 mm was used. The test specimen with 10 mm plaster was prepared without a reed mat since it is lightweight and plaster fastens easily to the timber surface. A reed mat was applied for the 30 mm thickness of plaster. The 30 mm plaster was applied in 3 layers, 10 mm at a time. Once the previous layer had dried a new layer was applied.

Both specimens were instrumented with five thermocouples on timber surface under plaster for temperature measurements. The positioning of thermocouples and the construction of tested specimen is shown on Fig.7.

Duration of the Test 1 for the specimen with a 10 mm plaster was 90 minutes. After 30 minutes a vertical crack was formed in the middle of the surface and by the time of 60 minutes the vertical crack had expanded to the side. Maximum width of the crack was about 1 cm. After 60 minutes the flames in the furnace developed fast and after 80 minutes the flames were extended all over the surface. No falling off of plaster was detected.

Test 2 with a 30 mm plaster was carried out 120 minutes. After about 17 minutes one horizontal crack formed in the middle of the surface. After about 38 minutes this crack had developed only horizontally. After 47 minutes the line had extended to the both sides of the specimen. No other cracks were detected. The crack was slowly developing wider but not significantly. Maximum crack width was detected around 1 cm. After 62 minutes a small vertical crack formed in the bottom of the specimen. No other cracks were detected. The plaster did not fall off during the test of 120 minutes. It remained solid except the formed dominant crack in the middle of the surface.

6.3. Results and analysis

For both tests, the temperature measurements were received by thermocouples from 5 positions marked as TC1 – TC5 on timber surface under plaster. The temperature measurements are shown on Fig.8 (a). The measurements of The start time of charring showed good agreement for both tests. For Test 1 the times for the temperature values to reach 300 ˚C on timber member were in between 7.8 and 10.4 minutes. For Test 2 the start times of charring were 28.3 and 30.5 minutes. The charring of timber was measured from the residual cross-sections. Fig.8 (b).

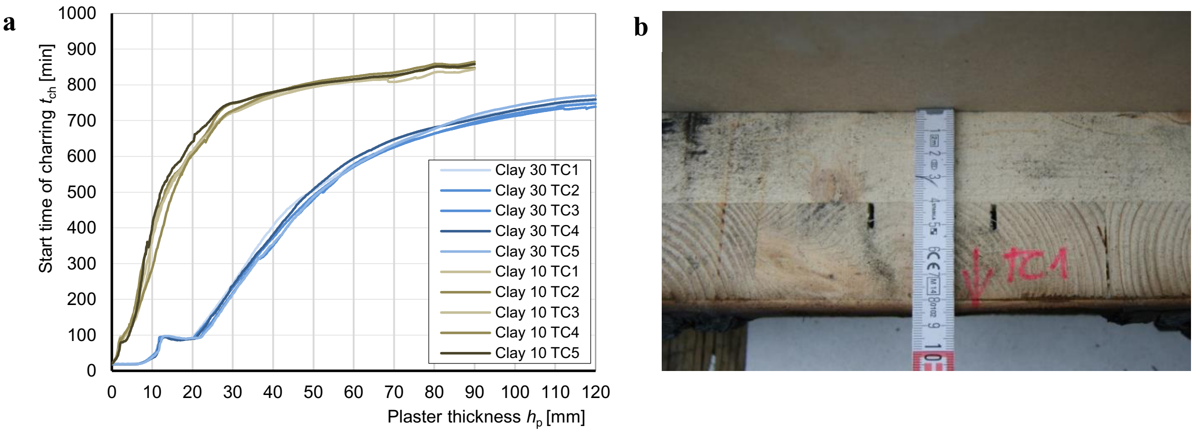

Fig. 8. (a) Temperature measurements on timber member below 10 and 30 mm plaster; (b) Documentation of the residual cross-section after fire test.

The charring depth measured in the position of thermocouples varies in maximum range of 7 or 8 mm. This difference could be influenced by minor factors as particularities of timber, positioning of the wood fibre, density of plaster, positioning of a plaster support or the slight differences in the temperature values in the furnace. In addition, in Test 1 the charring depth was observed more than thickness of one lamella - 40 mm. Based on the possible influences, the differences of charring rates are considered not significant. As a result, mean values for the start time of charring, charring depth, charring rate and protection factor are presented, see Table 2.

During the tests, the plaster did not show significant change in colour or structure. Despite one dominant crack in the plaster surface on both test, the surface of plaster remained solid and firm. The failure time of clay plaster was not detected due to the expansion of plaster to the furnace walls. However, a positive outcome is the ability of plaster to maintain its strength and structure throughout the testing. No plaster was falling off during the test. No thermal damage in the form of discoloration or burning was found. After the test, the wall was easily removed from the furnace.

Table 2.Tested specimens and measured start time of charring, charring depth, charring rates and protection phase factors

Test	Thickness of plaster [mm]	Plaster support	Duration of fire test [min]	Mean start time of charring [min]	Mean charring depth [mm]	Mean charring rate [mm/min]	Protection phase factor
Test 1	10	non	90	8.9	43	0.53	0.82
Test 2	30	reed mat	120	29.5	36	0.40	0.62

7. Discussion

7.1. Comparison of test results

The main fire design parameters for initially protected timber structures are the start time of charring and the charring rate of initially protected timber and the failure times. The failure times of plaster were not detected in the conducted tests. Therefore parameters of start time of charring and reduced charring rate are discussed in the following analysis.

The results of the described small scale and model scale studies are compared in Fig. 9. For reference, the design parameters for gypsum plasterboard are presented. Fig.9 (a) provides the comparison of the start times of charring. The results from the initial study appear most conservative. The results from the model scale show that the start time of charring of timber protected with a 10 mm of plaster is significantly increased compared to the small scale tests.

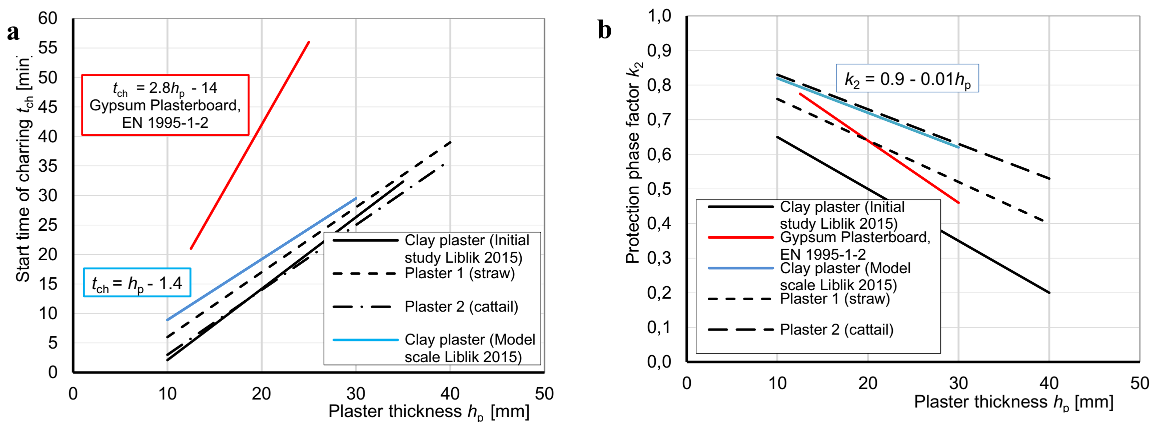

Fig. 9. (a) Comparison of start time of charring between small and model scale tests; (b) Comparison of the protection phase factor between small and model scale tests.

Since model scale furnace follows strictly the standard temperature-time fire curve ISO 834 [4] from the very beginning of the test, these temperature measurements are more accurate. The slower charring of wood at cone calorimeter test is caused by lower temperatures affecting the plaster surface after 30 minutes of fire exposure compared to the model scale tests. However, in general the results are in good agreement and no significant disagreement is noted. The comparison of the start time of charring in small and model scale clearly shows that the study in small scale roughly follows the temperature measurements in the model scale furnace.

The difference of the charring behaviour of protected timber is recognized between the initial study and the verification tests, see Fig.9 (b). The mean values are presented for each test. The verification tests in small and model scale show quite good agreement. However, the results of the initial study slightly differ. The difference in protection factor could be affected by the density of timber, the orientation of wood grain, the type of plaster and the preparation of the specimens as well as the heating conditions described above.

The verification tests in small scale of two different plasters from the market show good agreement to the results from the initial study by Liblik [3].

7.2. Suggestions for further research

Further investigation is necessary in order to improve the reliability of given expressions of clay plaster based on performed studies and analysis. Similar studies should be conducted with clay plasters from other manufacturers in Europe. Additional data is needed to widen the knowledge of the behaviour of clay plaster as a protection material.

Failure times of plaster should be determined with different substrates and plaster support systems. Further, the mechanical properties of the plaster, support materials and fixing are important to research in detail since the reduction of the charring rate applies only when the plaster is attached to the timber surface. Large scale fire tests are necessary to determine failure times.

The properties of clay plaster should be standardized in order to comply with the European system. Different manufacturers produce highly varying plasters in their characteristics. Clay plaster is a complex material and the possible combinations of plaster make it hard to gain a comprehensive overview of the fire technical properties in general. Fire technical properties of clay plaster should lead to thermal modelling. Lime plaster should also be investigated in the same way in the future.

8. Recommendations for the fire design

The following recommendations are based on the studies presented in this paper and no general conclusions must be made. The proposed formulas are limited by the tested clay plasters with a grain size of 0 – 4 mm.

Since the model scale test follows strictly the standard fire curve [2], the recommended formula for the start time of charring is based on the model scale test results. Although, for the calculation of the reduced charring rate a more conservative formula is presented. This is due to the various influencing factors explained above.

A recommended equation for the calculation of the start time of charring behind the clay plaster for design model EN 1995-1-2 [2] is presented (3).

$$t_{\mathrm{ch}} = h_{\mathrm{p}} - 1{,}4 \tag{3}$$

A recommendation equation for the calculation of the protection coefficient for charring behind clay plaster for the design model of EN 1995-1-2 [2] is presented (4).

$$k_2 = 0{,}9 - 0{,}01 h_{\mathrm{p}} \tag{4}$$

9. Conclusion

Test results show that traditional building material – clay plaster is suitable protection material for timber constructions in fire. The use of clay plaster as protection for timber structures delays the start time of charring and decreases charring rate of timber member as long as clay plaster is attached on timber member. Thickness of clay plaster is the most significant parameter to be considered to predict the charring behavior of timber. Since there is limited information about the fire technical properties of clay plaster, the proposed recommendations for the fire design of timber structures are based only on the studies explained in this paper. Further investigation is necessary in order to wider the database of tested clay plasters and application systems.

Development in standardization of clay plaster could lead to more accurate results in the fire tests. Investigations in the combination of timber and clay have a great potential to meet the demands and requirements for the entire building envelope in the future.

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